

## CHAPTER III.17

**agricultural fibers in the  
paper industry**

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Agricultural fibers were the first plant sources to serve as paper-making raw materials. As early as 500 B.C. pressed production of paper from wood began about 1800 A.D.

Wood, the basic raw material worldwide for pulp and paper, has for many decades dominated the market. Nonwood pulps account for about 3% of total production in the United States and about 5% of world production.<sup>1</sup> The total usage of pulp is so large that this 5% represents more than 7 million tons per year. Some 550 paper mills in more than 50 nations<sup>2</sup> now use nonwood agricultural fibers as raw materials.

Practically all countries have an increasing per capita demand for paper and paper products. The annual per capita consumption in the United States is about 570 pounds. As the developing countries improve their living standards, adopt modern marketing methods, and expand public education, they are consuming increasing quantities of pulp and paper.

Many areas of the world, including a large number of the developing nations, are deficient in the forest resources needed to provide sufficient pulpwood for the pulp and paper industry. Cellulosic fibers comprise a major structural component of most plants, and so nonwood sources represent a reservoir of raw materials for pulp. A sizable number of agricultural fibers (the term is used here to refer to all fibrous materials from nonwood sources) have been effectively used. Many annual plants have been investigated experimentally.<sup>3</sup> Pulp derived from agricultural fibers is useful either alone or in blends because of desirable properties that this pulp can give the end products.

Worldwide demand for paper and paperboard in 1985 is expected to be double that of 1965.<sup>2</sup> Although wood will retain its predominance, increased importance of agricultural fibers as world raw materials is anticipated.<sup>4</sup> Even in the United States, now that the switch from straw

**Table 1** *Some Dimensional and Compositional Characteristics of Selected Pulpwoods and Nonwoody Plants Processed for Pulps and Paper<sup>a</sup>*

Species	Fiber length (mm)	Fiber width ( $\mu$ )	Lumen width ( $\mu$ )	Cell-wall thickness ( $\mu$ )	Crude cellulose content (%)	Alpha-cellulose content (%)
Coniferous woods	2.0-5.7	32-44			60	39-45
Englemann spruce	3.5					
Longleaf pine	4.0				58	
Douglas fir	4.5				61	
Deciduous woods	0.6-1.9	38-50			45-62	38-49
Aspen poplar	0.4-1.9	10-40			63	
Black gum	1.7-1.8				61	
White maple	1.7				61	
Paper birch	0.8-2.7	20-30				
Nonwoody plants						
Sugarcane	0.3-3.4	9-45	16	5	48-58	30-37
Depithed	—	—			56-63	37-41
Cereal-grain straws	1.1-1.5	9-13			43-54	29-39
Rice straw	0.5-2.5	4-15	3	3.5	43-47	26-36
Bamboos	1.1-3.8	12-22	2-7	4-9	44-62	30-43
Reeds	1.0-1.8	8-20			46-54	36-43
Flax	4-8.5	10-37				
Esparto grasses	0.5-3.5	7-18	5.6-6.7	2.7	49-50	33-38
Mulberry, bast	2.3-9.9	17		5-8		

<sup>a</sup> Data have been adapted from the following sources:

P. R. Deshpande, *Indian Pulp and Paper*, 11, No. 1, 51-54, July 1956; No. 3, 154-7, September 1956.

B. B. Robinson and F. L. Johnson, "Abaca—a Cordage Fiber," Bureau Plant Industries, Soils and Agricultural Engineering, USDA Monograph No. 21, Beltsville, Md., October 1956, 130 pp.

F. N. Tamolang et al., *Tappi*, 40, No. 8, 673, August 1957; 43, No. 6, 529, June 1960.

Forest Products Laboratory, "Density, Fiber Lengths, and Yields of Pulp for Various Species of Wood," Technical Note 191, Revised, USDA, Forest Service, Madison, Wisconsin, September 1953.

H. J. Nieschlag et al., *Tappi*, 43, No. 3, 193-201, March 1960; No. 12, 993-998, December 1960.

E. C. Lathrop, T. R. Naffziger, and H. I. Mahon, "Methods for Separating Pith-Bearing Plants into Fiber and Pith," ARS 71-4, USDA Agriculture Research Service, Northern Utilization Research Branch, Peoria, Illinois, March 1955, 49 pp. plus 28 tables and 20 figures.

to hardwood for corrugating medium is accomplished, the usage of non-wood fibers will grow.<sup>5</sup> However, in some localities pulp is entirely from nonwoody fibrous plants.

In the United States usage of agricultural fibers is expected to increase, but at no greater than a 5% average annual rate—half that of the worldwide average.<sup>5</sup> Utilization of agricultural fibers in this country was extensive up through the early 1940s when more than 500,000 tons of straw and another 400,000 tons of other fibrous materials (exclusive of rags and wastepaper) were consumed.<sup>6</sup> Then economic factors caused a gradual decline in use of straw, until now no paper pulp mills in the United States rely on wheat straw as a raw material. Use of byproduct materials such as bagasse and flax straw are expected to continue; research is also being carried out on kenaf.<sup>5, 7</sup>

Typical dimensional and compositional characteristics of selected woods and nonwoody plants are shown in Table 1.<sup>3</sup> Usually, agricultural fibrous raw materials are higher in ash and hemicellulose contents and lower in lignin than either coniferous or deciduous woods. Cellulose contents are comparable. Some authors<sup>8</sup> subdivide agricultural fibers into the following groups: (a) straw and grasses, other than bamboo, (b) canes and reeds, (c) woody stalks with bast fibers, (d) bamboos, (e) leaf fibers, and (f) others. Comparison of chemical characteristics leads to the following conclusions:

1. Lignin content is rather low in bast and leaf fibers, but it is high in bamboos and woody portions of the stems of dicotyledons from which bast fiber has been removed. Straws and grasses have less lignin than canes and reeds, but both groups are lower in lignin content than pulpwoods, bamboos, and woody stem portions.

2. Bast fibers are low in hemicelluloses, whereas straws, grasses, and reeds are high. Deciduous pulpwoods and leaf fibers are higher than coniferous woods, approaching the straws in amount of hemicellulose. Bamboos and woody stems of dicotyledons usually contain less hemicellulose than straw.

3. Bast and leaf fibers, as well as bamboos, are higher in cellulose content than many of the other agricultural fibers. Plant stalks can vary greatly in cellulose, ranging from about 25% to 60% total cellulose and about 15–40% alpha-cellulose.<sup>3</sup>

Annual dicotyledonous plants need not be separated into bast and woody portions before pulping since such a procedure may be uneconomic unless a premium-grade speciality paper from the bast is required. An entire kenaf stalk, including both bast and woody fractions,

**Table 2** *Conditions and Results for Rapid Continuous Pulping of Certain Annual Fibrous Materials and Bamboo*

Fibrous Material	Process	Pulping Conditions			Results	
		Na <sub>2</sub> O <sup>a</sup> (%)	Time (min)	Pressure (psi)	Yield (%)	K No.
Wheat straw <sup>b</sup>	Soda	4.6	8	75	67	—
	Soda	10.0	8	80	50	—
Rice straw <sup>b</sup>	Soda	9.8	5.5	100	39	4.9
Bagasse <sup>c</sup>	Sulphate	12.0	10	130	52	7.5
Reeds <sup>b</sup>	Soda	13.8	20	130	48	15.0
Esparto	Soda	12.4	20	120	52	6.0
Napier grass <sup>c</sup>	Soda	15.0	30	150	44	15.0
Bamboo <sup>d</sup>	Sulphate	18.2	30	130	45	10.0
Cotton linters	Soda	5.6	18	100	75	2.7

<sup>a</sup> Chemical applied on dry, raw fiber basis.

<sup>b</sup> Uncleaned raw fiber used.

<sup>c</sup> Depithed or cleaned raw fiber used.

<sup>d</sup> *Bambusa arundinacea* from India.

is high in cellulose and provides good pulp yields.<sup>9</sup> Since blending of fibers for paper is customary anyway, both the long bast fibers of kenaf and the shorter woody fibers make individual contributions to sheet properties.

With regard to fiber dimensions, there are again wide ranges within each plant group. The longest fibers are found in bamboos, leaf fibers, and the bast fraction of dicotyledons. These fibers are of the same order of length as those of softwoods, though some bast and leaf fibers may be considerably longer. The straws, grasses, and reeds contain shorter fibers similar to the hardwoods. Shortest of all fibers are those in the woody portions of dicotyledon stems; these fibers contribute to properties of pulp blends but by themselves do not make strong papers. An extensive compilation and interpretation of fiber dimensions have been reported.<sup>10</sup>

Alkaline pulping reagents have been preferred for agricultural fibers; many of these raw materials require the mild treatments for their pulping and also for refining the pulps. Conditions for the continuous pulping of annual fibrous materials are listed in Table 2.<sup>11</sup> Continuous pulping techniques, with compaction, are preferable for agricultural

fibers because their large bulk uses excess digester capacity and necessitates too high a liquid-solids ratio in stationary digesters.

USDA economists<sup>12</sup> have calculated that kenaf should be able to compete with corn or soybeans in many farming areas of the South, and could be developed as a papermaking raw material.

## CEREAL STRAWS

Cereal straws (wheat, rice, oats, rye, barley, and flax), but particularly wheat straw, have been pulped in various parts of the world since the early part of the nineteenth century.

Before 1950 most straw was pulped by the lime process. This was later replaced by the neutral sulfite process, which gave higher yields and better quality pulp (8). Major use of the pulp was for strawboard, egg-case fillers, and corrugating paper. As late as 1950 more than 650,000 tons of pulp was produced annually from wheat straw (14). Wheat straw is no longer used for this purpose in the U.S. Although straw is available in the field in large amounts, with modern farming techniques the grain is mechanically harvested and recovered in the field and the straw is no longer collected and is not available at low cost at central locations. Collection, transportation, and long-term storage for large, modern, year-round operating pulping plants are uneconomical. Except where special and unique properties are desired, straw cannot compete with wood. Flax straw is an exception and is discussed separately.

Straw is extensively used in certain countries where wood supply is limited and modern mechanized harvesting is not extensive. Historically, as the demand for foods and papers increases, land values become expensive and such agricultural residues as straw become uneconomical.

More than 1 million tons/yr of wheat straw is a waste of cereal production and is plowed back into the soil, although formerly used as a paper raw material. Wheat straw was formerly an important pulping raw material in the United States. The first U.S. paper mill in which wheat straw was the raw material was installed about 1831 in Chambersburg, Pennsylvania. Its capacity was about 1 ton/day. At one time, there were at least 30 plants that used wheat straw as their raw material. As late as 1950, more than 650,000 tons of pulp were produced annually from the straw. Major use was for strawboard, egg-case fillers, and corrugating paper. Wheat straw has no significant market for these purposes now.

The total amount of wheat straw in the fields has not materially

**Table 3** *Wheat Straw Board: Plant Size versus Board Cost (Hypothetical Plant)*

Production, tons/day	75	150	225
Capital cost, million dollars	9.04	12.3	15.6
Board cost (Dollars per Ton)			
Straw (\$16 per ton)	29.9	29.9	29.9
Manufacturing costs	88.1	65.5	59.3
Fixed costs	50.7	34.8	29.8
Total factory cost <sup>a</sup>	168.7	130.2	119.0

<sup>a</sup> Exclusive of sales and profit.

changed for many years. (The newer wheat semidwarf varieties have had only minor overall effects in most regions, but could be significant in the future.) However, the location and condition of the straw have completely changed. The wheat grain is mechanically recovered in the field and the straw is left behind and distributed on the ground. Straw is no longer available at a low cost in straw stacks at central locations, as collection becomes a separate operation. The straw cost and the supply available in collected form have thus become undependable.

The original straw-based plants were located in the Eastern Midwest. Relocating plants to follow the shift in straw supply westward was not feasible. Therefore, as the pulping plants became obsolete, they were dismantled or were more economically modernized to use readily available wood. Many of these older straw plants were also too small for efficient economical operations.

Wood yields per acre are normally 1-2 tons/yr. However, trees must be grown at least 5-10 yr before they can be harvested. Thousands of acres (particularly in the South) are already being converted to the production of annual crops.

Feasibility studies on straw pulping have been made and published by several states, among them Colorado, Kansas, Nebraska, North Dakota, and South Dakota,<sup>38-42</sup> showing that sites are available where water, straw, labor, land, and basic requirements for large straw pulping plants could be met. Pulping plants do not exist in these regions and locations now. The technical and economic information on straw pulping is plentiful and readily adaptable to local conditions.<sup>2-5, 9, 13-15, 18-22, 25-28, 30-32, 34-37</sup>

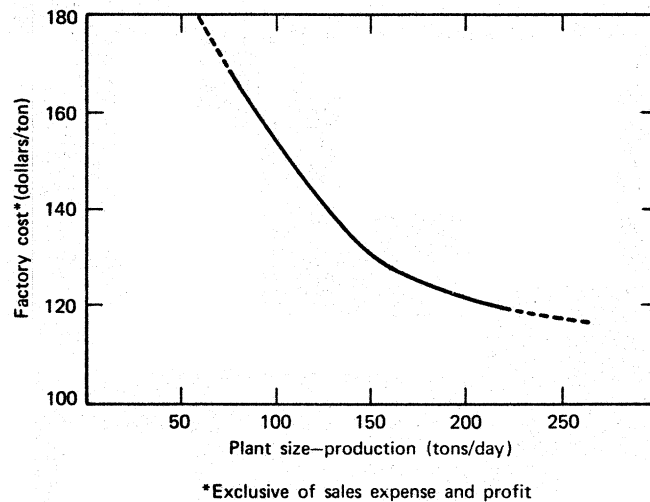
There is an adequate supply of wheat straw in several U.S. locations for a pulp plant. Only a fraction of 1% of the over 100 million tons

produced annually is collected for commercial use. Adaptation of the combining operation would be required to simultaneously collect the straw in a suitable form (i.e., bales) for transportation to the processing plant.

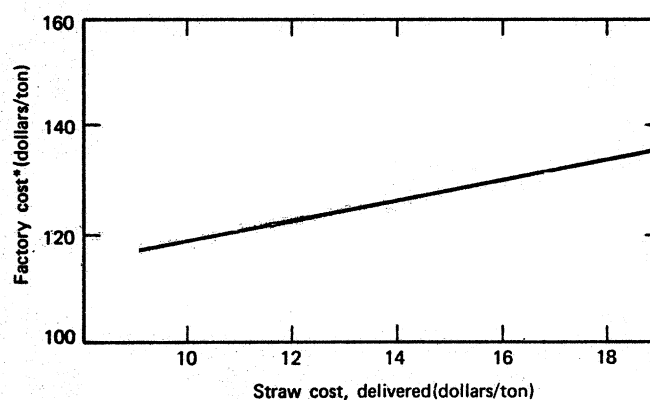
Only a large, continuous, automated plant is economically feasible. Unit costs increase rapidly below 200 tons/day, and plants with larger capacity reflect some further economic advantage but at a decreasing unit rate.

USDA research on agricultural residues (including straw) was discontinued around 1960. Based on an integrated, continuous straw-pulping and corrugating board plant located in a major wheat production region, Table 3 and Figure 1 give estimated cost in plants producing 75–225 tons/day. The cost for board of about \$168 per ton in a 75-ton/day plant is reduced to about \$130 per ton in a 200-ton/day plant. Capital cost per ton of capacity is also reduced by about 35%. Paperboard wholesale prices are in the same order-of-magnitude as in the 200-ton plant.

The effects of straw price on board price are shown in Figure 2. A change of \$1 in straw-delivered price changes the board price about \$1.86 per ton. This effect is practically the same (regardless of plant size) in a large continuous plant.



**Figure 1.** Wheat straw board; plant size versus board cost.



\*Exclusive of sales expense and profit

**Figure 2.** Wheat straw board; straw cost versus board cost (150 ton/day plant).

## FLAX FIBERS

Flax straw for papermaking is a by-product of the production of flaxseed for linseed oil. Fiber flax grown for the production of linen is normally too expensive for the production of paper, although a small amount of waste fiber and textile cuttings or scraps are available. Almost all seed flax is grown in the North Central portion of the United States (Minnesota, the Dakotas, and Montana) and in Texas.

Flax straw is 12–15 in. long and relatively strong. The dry straw is baled and shipped to special pulping plants for the production of such speciality products as cigarette paper, Bible paper, carbonizing tissues, scuff-resistant papers, and currency paper. Flax fiber length averages about 25 mm but varies widely.

Only a small portion of the available flax straw is now collected. Of the approximately 500,000 tons potentially available, only about 40% is considered to be of suitable quality; one-third to one-half ton of straw per acre of flax is about normal. The price paid for baled straw delivered at a local collection point is \$15 to \$16 per ton. Approximately \$3.50 per ton is paid for usable flax straw in the field. Two companies process flax straw into paper in the United States.

The United States accounts for about 15% of the world flax acreage (approximately 15,000,000). Other large flax-growing countries are



Canada, Argentina, and India. Some flax is grown on all continents and small amounts of flax straw are utilized for paper in all world regions.

## ESPARTO

Two perennial grasses are native to the arid regions of North Africa and southern Spain, *Stipa tenacissima* and *Lygeum spartum*, known as esparto. The rushlike plant has wiry stems up to 3 ft tall that are usually hand-harvested by plucking, to leave the roots for regrowth. The grass grows in clumps and is shipped in bulk or bales.

A British patent granted in 1839 describes the preparation of paper from esparto. Early usage of esparto for fine papers was mostly in Great Britain, where it was introduced by Thomas Routledge in the middle of the nineteenth century. Production was more than 300,000 tons in 1955.<sup>43</sup>

Caustic soda is the preferred cooking chemical. At least two modern mills have been erected for pulping esparto with 13–16% percent NaOH. One in Tunisia<sup>44</sup> has a capacity of 80 tons/day of bleached pulp and uses continuous cooking for 20 min at 120 psi. The other, a 55-ton/day pulp capacity mill in Spain<sup>45</sup> employs three stationary batch digesters with all modern controls.

Esparto fibers are round and fairly uniform; they have a moderate average length of 1.1 mm and a high ratio of length to width. Although esparto paper is bulky, it has high opacity, closed formation, resilience, and good dimensional stability with respect to moisture changes. These characteristics make the paper valued by printers for its flatness, and ink receptivity. New pulping facilities may continue to be placed in Mediterranean areas close to the centers of esparto production. Total availability of esparto is about 500,000 tons/yr.<sup>46</sup>

Esparto has long been the basic paper fibre for the Argentine region, which does not have trees for pulp. Cellulosa Argentina makes all the paper for Argentine money from esparto grass. Commercial stationery has the same basis.

## SORGHUMS

Sorghums are high-yielding, coarse annual grasses, under wide cultivation; there are forage sorghums, grain sorghums, broomcorn varieties, and sweet sorghums. They are good crop plants and some seem to have a fibrous character for pulping; as a primary crop for

**Table 4** Comparative Chemical Characteristics of Mature Kenaf, Spruce and Maple

Characteristics (Moisture-free basis)	Kenaf			Spruce (%)	Maple (%)
	Green		Dry		
	Florida (%)	Illinois (%)	Illinois (%)		
Cellulose					
Alpha, corrected	38.4	32.0	38.2	39.4	39.1
Crude	57.3	48.4	56.1	60.0	60.2
Lignin	14.6	13.9	17.1	27.6	23.3
Pentosans	24.6	21.4	23.1	10.6	22.6
Ash	2.5	3.7	1.9	0.5	0.5
Alcohol-benzene solubles	4.7	5.6	3.3	2.4	2.4
Solubles in 1% NaOH	27.9	39.0	27.8	13.9	15.7

pulping sorghum has been under study in both France<sup>47, 48</sup> and in Hungary.<sup>49</sup>

## REEDS

Two common reeds, both in the grass family, are *Phragmites communis* and *Arundo donax*. The *A. donax* reed, a dryland plant native to the Mediterranean countries, is widely distributed through practically all of the warm-temperate and subtropical countries of the world<sup>50</sup>; it has been given consideration as a source of industrial cellulose in Italy and Argentina.<sup>51</sup> The swamp reed, *P. communis*, is a perennial that grows in river deltas and along banks, marshes, and lake shores in many areas of Eastern Europe, Africa, Asia, and South America. The *P. communis* reeds grow to 10–15 ft tall and may produce as much as 4 metric tons of dry matter per acre.<sup>46</sup> In colder areas of Russia, mainland China, and Rumania, mechanical harvest is carried out in winter when the ground is frozen. Elsewhere, harvest is by amphibious vehicles or by hand from small boats. Reeds provide short to medium-fibered pulps that have some of the softness and bulk characteristics of esparto.

Because of the amount of *Phragmites* reeds available as raw material, there are established pulp mills based on the natural stands. Rumania and the U.S.S.R. produce some 200,000 metric tons of reed pulp annually. Four mills have been built in Russia since 1961.<sup>52</sup> In one of

these, a continuous digester provides 46–48% pulp yield, from a 38-min cook. Egypt has a small reed pulp mill in which the equipment is the same as used for rice straw. Alkaline reagents (caustic or kraft chemicals) are used for fully cooked pulps. Neutral sulfite may be used for semichemical pulp.

## KENAF

Kenaf (*Hibiscus cannabinus*) has traditionally been grown as a textile type of fiber crop in many regions, using the bast fiber, or about 20% of the total dry weight of the stalk. The remaining portions have been discarded.

Through pulping of the whole stalk, kenaf has become a paper-making raw material. Typical comparative chemical characteristics of kenaf and wood are shown in Table 4; comparative fiber characteristics in Table 5 and chemical pulping of kenaf, in Table 6.<sup>53</sup>

Kenaf produces higher annual fiber yields per acre than wood in the preferred areas where it grows in the United States—usually several times higher. Yields up to 10 tons or more of dry matter per acre per year have been obtained.

## JUTE

Jute is an annual plant (*Corchorus*) that is cultivated in many countries. Yields are maximum where a warm climate and heavy rainfall

**Table 5** Comparative Fiber Characteristics of Mature Kenaf, Spruce, and Maple

Characteristics	Kenaf			Spruce	Maple
	Green		Dry		
	Florida	Illinois	Illinois		
Fiber length (mm)					
Bast	2.16	2.32	2.52		
Woody	0.45	0.48	0.51		
Combined	1.15	1.22	1.21	3.16	0.76
Fiber width ( $\mu$ )					
Bast	13.6	15.7	15.9		
Woody	32.0	30.1	30.7		
Combined	—	—	—	43.8	20.2

**Table 6** *Chemical Pulping of Kenaf<sup>a</sup> as Compared to Wood*

Property	Kenaf			Woodpulp	
	Green	Dry	Softwood	Hardwood	Softwood
	Florida	Illinois	Illinois		
Crude yield (%)	58.0	49.1	52.7	52.0	58.0
Screened yield, 8-cut (%)	54.8	46.9	49.6	—	—
Fines (%)	3.1	2.1	3.1	—	—
Beater evaluations (unbleached)					
Characteristics at 600 ml S-R					
Burst factor (g/cm <sup>2</sup> )/(g/m <sup>2</sup> )	63.4	72.0	73.5	25	62
Breaking length (m)	11,800	11,400	11,600	4700	9300
Tear factor (g/(g/m <sup>2</sup> ))	80	94	93	43	120
Folds, Schopper No.	1360	1210	920	100	1600

<sup>a</sup> Cooking 2 hr at 170°C, 21% chemical.

prevail during the growing season; Pakistan, Thailand, and India are the major world producers. The bast fiber of jute is normally separated from the woody portion of the stem and used as a textile fiber. Jute and kenaf fibers are often used interchangeably for burlap, sacking, twine, linoleum, and rug backing. Jute bast fiber may be pulped alone or the whole stalk could be used as a papermaking raw material.

At present most of the jute fiber used for pulping comes from waste textile fibers, such as bags and wrappings, and from new burlap cuttings. Jute fiber normally averages about 2 mm in length, varying from 1.5 to 5.0 mm. Bleached fiber always retains a light yellow color because of the lignin complex.

In general, the physical data and pulping information presented for kenaf also apply to jute. Jute is particularly used for tear- and scuff-resistant papers and for heavy-duty multiwall bags.

## **HEMP**

The hemp (*Cannabis sativa*) stalk, like other annual herbaceous dicotyledons, is composed of a central core or woody portion (hurds) and the outer bark or bast. Usually the long, flexible bast fiber is obtained by water retting the stalks; it is utilized as a textile fiber. Hemp for pulp and papermaking then becomes available to industry as secondary or waste fiber, such as used sailcloth, webbing, sacking, carpeting, cordage, twine, rope, or coarse fabrics. Hemp bast fibers are similar to those of flax. Fiber length averages about 22 mm, varying from 5 to 55 mm.

For pulping, hemp rope is chopped to about 2-in. lengths and the fibers after loosening are pulped with lime or caustic soda (about 20% based on dry fiber). In Europe, hemp fiber has been used for speciality papers for the manufacture of such products as Bibles and cigarettes.

Hemp fiber, like that from flax and jute, imparts durability and high tear resistance when added to furnishes for making heavy-duty, strong papers or light-weight papers of high strength. There is some production and usage of hemp in Europe, particularly in France. In 1964, production was about 4800 hectares, of which about 1500 was for papermaking. In the United States there is minimal hemp fiber that reaches the industry as old rope or the like.

## **BAMBOOS**

Botanically, bamboos are woody stemmed perennial grasses. The stems (culms) are usually hollow between joints (nodes), ranging in height when mature from a foot or two to 100 ft or more. There are 700 or more known species of bamboos. These are usually subdivided into

the clump types (tropical) and the running types (found in temperate zones); the two terms refer to the habit of rhizome growth. Like other perennial grasses bamboos may flower, go to seed, and die at unexpected intervals. Such potential loss of raw material from large stands for several years pending re-establishment must be considered, so as not to have a pulp mill become too dependent on a single bamboo source.

In the Orient, bamboo was first used for papermaking many centuries ago. In India it is the major papermaking raw material and accounts for almost three-fourths of that country's pulp production.<sup>54</sup> In 1965, the amount of bamboo pulp produced exceeded half a million tons. Commercial use of bamboo on a lesser scale, in one or several mills, also exists in Thailand, Pakistan, Indonesia, Japan, Taiwan, mainland China, the Philippines, and Brazil. Natural bamboo stands in India reportedly yield 0.5–0.75 ton/acre/yr, but under cultivation, yields of 2–4 tons/yr have been indicated. The Indian bamboo pulps are primarily bleached pulps for printing papers of various types.

Bamboo fibers typically are long, slender, and pliable. They contribute high tear resistance, as well as softness and smoothness, to paper sheets. Bamboo pulps are frequently blended with other pulps to improve burst and tensile strengths. The softness and flexibility of the bamboo fibers makes the pulp useful for tissue as well as for bond and book papers.

The wall of the bamboo is dense, which aids digester efficiency but requires special effort for effective chipping and penetration of cooking liquor during pulping.

Bamboo is pulped by an alkaline procedure, in a single-stage kraft process. Pulped at an active alkali level of 16–17% (as  $\text{Na}_2\text{O}$ ) with kraft chemicals, the yield of unbleached (bleachable grade) pulp is about 48%. The chemical requirement for bamboo is thus somewhat higher than for other agricultural fibers. Most of the Indian pulp mills still use batch digesters, though one or two new ones with continuous pulping equipment are operating.

Bamboo, grown on a limited basis in the United States for more than 50 years, has not been utilized in for pulp.

Several pertinent reviews and recent technical articles on bamboo are available.<sup>54-59</sup>

## **LEAF FIBERS**

Leaf fibers, such as abaca, sisal, henequen, caroa, and phormium, are used primarily for cordage and textiles. The fibers occur in long

strands, which are separated by hand operation or machine decortication. For paper the fibers, or old cordage, are first cut or chopped before pulping with kraft chemicals or caustic soda. Pulp yields for the manufacture of papers that require maximum tear strength are high. The strongest bag and wrapping papers, currency, and papers that require high scuff resistance are produced from these leaf fibers. Tea bags and stencil sheets are made from abaca (manila hemp). Only small volumes of leaf fibers are used for speciality papers.

## OTHERS

Limited quantities of cotton linters and rags are chemically pulped. Normally, 170–190 lb of linters are obtained per ton of cottonseed. Most of the fiber lengths used for papers are the lowest grade and are less than 4–5 mm long. The linters contain approximately 70–85% alpha-cellulose.

Cotton rags are the basis for most rag papers. The cotton fiber itself in the rags is 10–30 mm and more in length. Primarily rags are wastes or by-products from textile mills.

The quantities of rags and linters used for papers are approximately 500,000 tons/yr, about one-half of which is rags. Chemically processed linters and rags appear mainly in fine-grade writing papers that command a premium price. Low-grade rags often go into roofing paper.

## BUSHES AND BRUSH

Recent success in growing annual fiber crops for papermaking raw materials has renewed interest in the farming and pulping of wood bushes and brush. It is too early to determine the economic success of such operations. Such fast-growing woods as the silage sycamore and cottonwood are known to be under investigation by commercial companies.<sup>32</sup> Wood yields two to three times that of trees have been reported. However, such production would require major revisions in current tree farming and pulping practices. This development resembles the growing of nonwoody annual crops, such as kenaf.

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